Assimilating Data into a Circulation Model

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LONG-TERM GOALS

The long-term goal of this study is to build an integrated circulation observation/prediction system where a variety of remote and in situ field observations can be assimilated into a numerical model to provide near real-time nowcasting and forecasting capabilities in the nearshore.

OBJECTIVES

Our objective is to construct an integrated modeling capability that will rely on advancements in both models and spatially dense measurements of nearshore currents. The system consists of an existing numerical model of the depth- and phase-averaged equations of motion governing the temporal and spatial evolution of the nearshore circulation (Özkan-Haller and Kirby, 1999), and will utilize observations of surface current patterns obtained using Particle Image Velocimetry (PIV) techniques

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14. ABSTRACT
The long-term goal of this study is to build an integrated circulation observation/prediction system where a variety of remote and in situ field observations can be assimilated into a numerical model to provide near real-time nowcasting and forecasting capabilities in the nearshore.

15. SUBJECT TERMS

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applied to a video system (PI's Lippmann and Holland) as well as other remotely obtained data such as surf zone width or proxies for radiation stress gradients (PI Holman). Our focus is on a thorough understanding of the assimilation techniques and the implementation into the circulation model, and testing of the modeling scheme as part of the Nearshore Canyon Experiment (NCEX) planned for the fall of 2003 (see http://science.whoi.edu/users/pvlab/NCEX/index.html). Our specific objectives are to:

- Adapt an existing nearshore circulation model based on the depth- and phase-averaged nonlinear equations of motions (Özkan-Haller and Kirby, 1999) to incorporate (assimilate) observations of currents. Test resulting model with synthetic and existing data.

- Test the assimilation techniques with field data obtained by collaborating groups as part of NCEX. This work will begin on-site during the experiment, and continue in the subsequent year following its conclusion.

- Develop and implement methods of data assimilation that will aid in the incorporation of non-traditional measurements that can be obtained from surf zone video observations, such as surf zone width and energy dissipation.

APPROACH

Data assimilation methods provide a formal means for combining models with measurements to generate solutions that constitute a best fit to all relevant data while satisfying the constraints imposed by the modeling equations. Our focus is on the thorough understanding of the assimilation techniques and their implementation into the circulation model and testing of the modeling scheme as part of the NCEX field experiment. . Two distinct strategies are being examined:

1. The first strategy involves computationally efficient sequential estimators that correct forward model output using available data, but do not tune model parameters (such as frictional coefficients). We anticipate being able to model a "strip" of the beach that extends alongshore for several kilometers and is bounded by the shoreline and the 10 m contour in the cross-shore direction (see Figure 1).

2. The second strategy involves more computationally expensive inverse models that are used to adjust free model parameters to achieve an optimal fit to the data. Inverse methods are based on the derivation of an adjoint model which propagates information backwards in both space and time. The forward and adjoint models are coupled and are solved iteratively. This process is outlined schematically in Figure 2. Using this technique we anticipate modeling a portion of the NCEX site, such as the area around Black's beach, in detail.

WORK COMPLETED

We have been working on three fronts. First, in order to make on-site computations during the field experiment possible we are revising the existing circulation code to increase its numerical efficiency. Secondly, we have been investigating methods by which start-up errors associated with sequential methods can be reduced. Lastly, in relation to the development of an inverse model we have been deriving the adjoint equations for the nearshore circulation model at hand. We are simultaneously researching solution methods to the coupled forward and adjoint problem associated with the inverse modeling scheme.
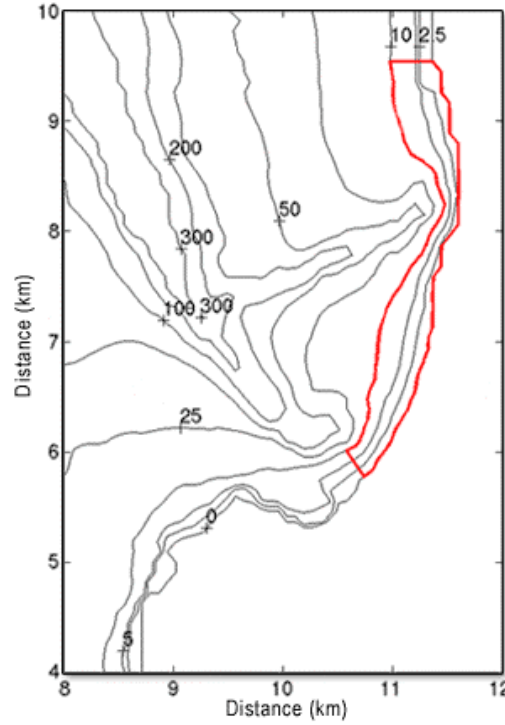
Figure 1: Domain of interest for model simulations (outlined in red). The longshore extent of the domain of interest is chosen to coincide with the area that will be viewed with the video cameras. Note that the model domain is bounded by curvilinear lines in the cross-shore direction. The off-shore boundary coincides with the 10m-contour. The location of the shoreline boundary can vary to account for the tidal elevation and any shoreline runup due to low frequency motions.
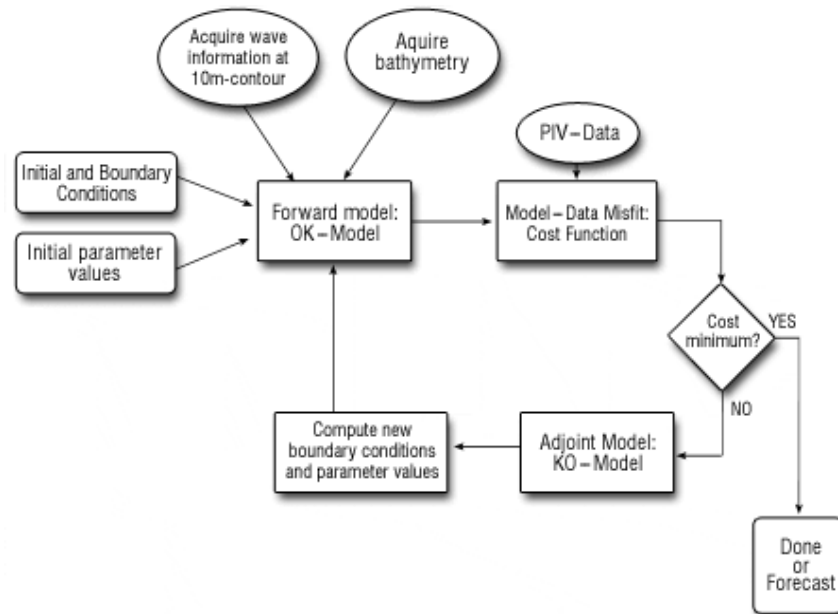

Figure 2: Flowchart of an inverse modeling scheme.

RESULTS

We have invested some resources in revisions of the existing code to increase its numerical efficiency. Our efforts to streamline the nearshore circulation code have resulted in an approximately 30% speedup of the code.

Our efforts related to sequential estimators have focused on methods to reduce start-up errors associated with these methods, which present no formal means for tuning model parameters. Since empirical coefficients such as the friction coefficient may initially be poorly constrained there may be large start-up errors as the model results adjust to the available data over a finite amount of time. One of our initial tasks has been to identify ways to compensate for start-up errors that arise due to identifiable reasons, such as an error in the initially assumed friction coefficient. We have applied one possible algorithm to the prediction of the wave-induced longshore current on a plane beach. For bathymetry and wave conditions that correspond to February 4, 1980 at Leadbetter Beach, CA (see Thornton and Guza, 1986) we generate a longshore current profile utilizing an initial guess for the friction coefficient. The resulting longshore current profile is depicted by the blue line in upper panel of Figure 3. To test our idea, we construct virtual ``measurements'' (marked by the red symbols) that indicate that the measured longshore current is significantly weaker. We compute a bulk estimate of the mismatch between the observed longshore current values and the computed values that correspond to the same cross-shore locations (indicated by the black diamonds), and arrive at a value of the rms error. Reducing the current profile by the amount of the error variance yields qualitatively better agreement (green line). However, this can be formally achieved by increasing the friction coefficient (possibly in mid-simulation). The result is a significantly reduced data-model mismatch (see Figure 3, lower panel). It is noted that a further iteration with this method does not reduce the rms error further. However, the objective here is not to minimize the mismatch. Instead, the idea is to reduce the mismatch between data and model to prevent large start-up error in the sequential estimators which will be formally incorporated.

Our efforts related to inverse models have focused on the derivation of the adjoint equations related to the circulation model at hand. We are at this point concentrating on the depth-averaged equations of motion and are initially neglecting effects related to wave-current interaction and shoreline runup due to low frequency motions. The adjoint equations are coupled with the forward equations and we are considering several solution methods; among them are gradient descent algorithms and representer solutions. We are currently investigating the possibility of a collaboration with the group of Andrew Bennett as part of the Inverse Ocean Modeling System (Chua and Bennett, 2001) being developed with the leadership of Oregon State University. In relation to that effort, the lead-PI has attended a 2-week summer course on data assimilation to aid in the model development

IMPACT/APPLICATIONS

This study will further our understanding of assimilation techniques and their application in the neashore region, particularly in relation to spatially non-uniform and possibly discontinuous data sets. The model development undertaken here will increase the scientific understanding of the circulation in the nearshore and will also pave the way to operational models for nowcasting and forecasting in the nearshore region.
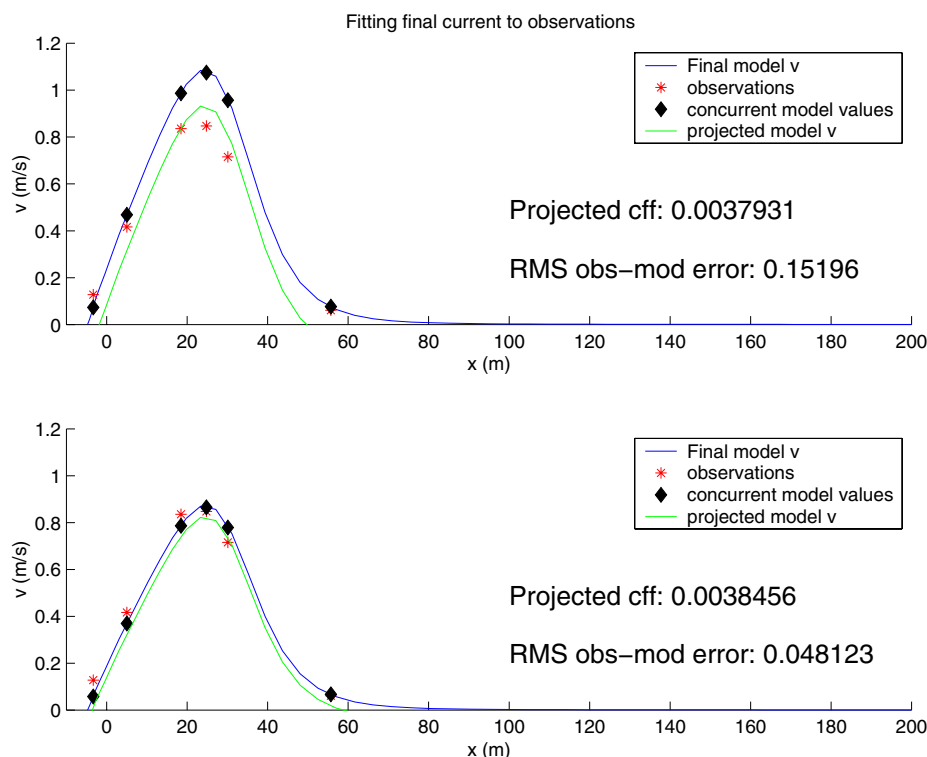
Figure 3: (upper panel) Longshore velocity component (blue line) from initial run using a coefficient (cff) of 0.003. Comparison of "data" (red stars) and concurrent model values (black diamonds) results in anRMS error of ~0.15. A projected cff for a subsequent run is computed to be about 0.0038. A projected velocity profile for this cff is shown in green. (lower panel) Longshore velocity component from subsequent run with cff equal to 0.0038. Note the adjustment of the velocity profile to be much closer to the "data".

TRANSITIONS

The work on the project will lead to a robust modeling tool which is capable of predicting the time-varying circulation field in the nearshore region. The model code will be available to the engineering and science communities. The resulting model can at a later date be transitioned to allow for operational use in hindcasting, nowcasting and ultimately forcasting circulation in the nearshore region.

RELATED PROJECTS

This effort is part of an overall program related to the Nearshore Canyon Experiment (NCEX) planned off the coast of CA in the Fall of 2003. Close collaborations are planned with other researchers involved in NCEX-related projects. Also, knowledge gained about the assimilation methods used here can benefit the ongoing NOPP project (Lead P.I. J.T. Kirby) "Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean".

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